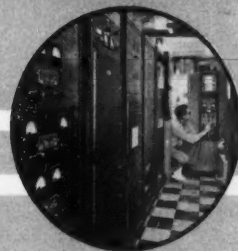


## research trends

CORNELL AERONAUTICAL LABORATORY, INC., BUFFALO 21, NEW YORK



# Driving Comes Into the Laboratory

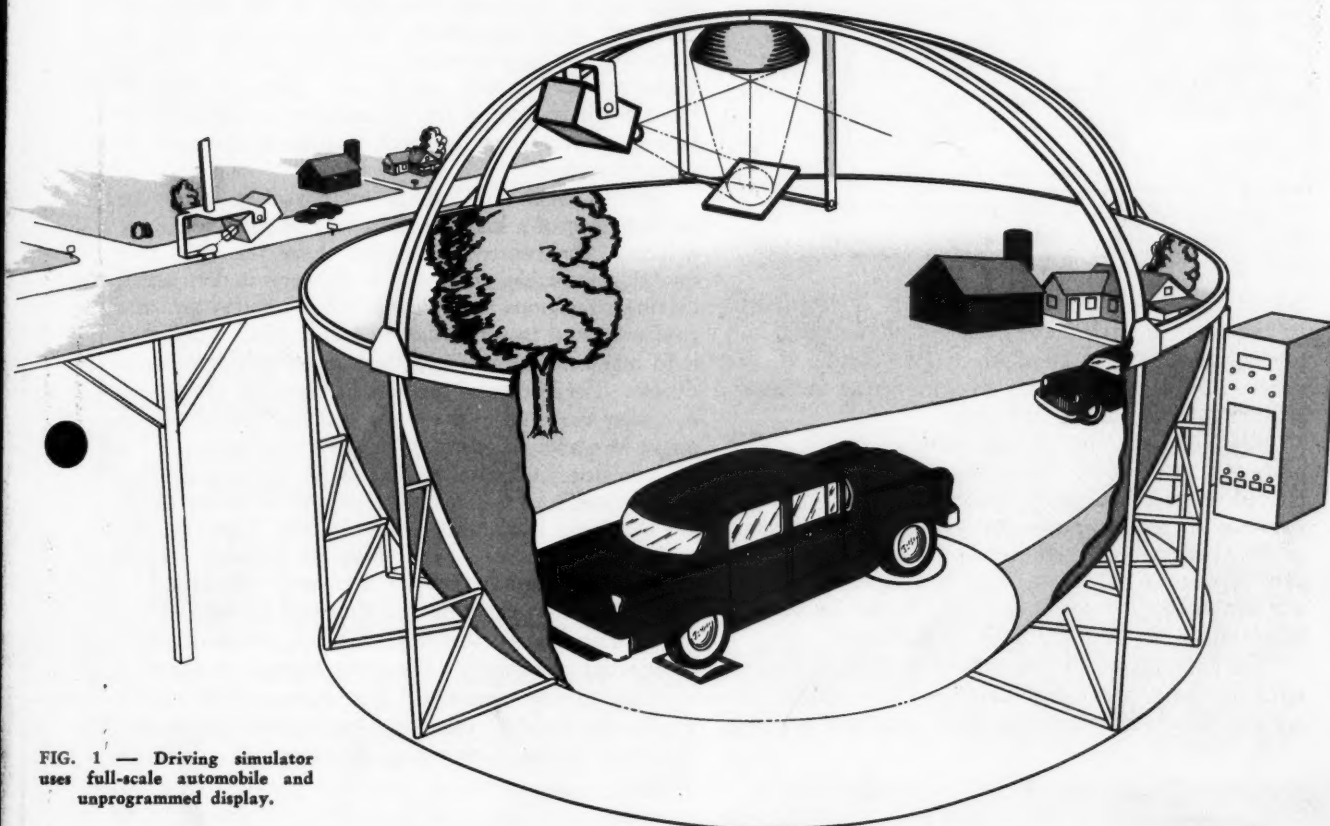


FIG. 1 — Driving simulator uses full-scale automobile and unprogrammed display.

By CHARLES H. HUTCHINSON

### Exploring the Development of a Driving Simulator

**A** VITAL question for highway transportation systems is "Can accidents be reduced, and if so, how?" The answer appears to be yes, but the methods to be used are not quite so apparent. Such commonly accepted means as driver education, strict law enforcement, reasonable speed limits, and improved highway systems may all make contributions. None of these devices, however, can effect the drastic reduction that is hoped for.

How can a major reduction be achieved? From the research point of view, understanding all of the elements

which make up the driving system is the first step. Application of this knowledge to engineering improvements of the system is the second.

#### Understanding the Elements

Three basic elements of highway transportation systems are man, medium, and machine — i.e., the driver, the road, and the vehicle. In a broad sense all of them are dynamic elements — the road contains dynamic traffic features as well as fixed topography; the vehicle's dynamics appear as responses to road and

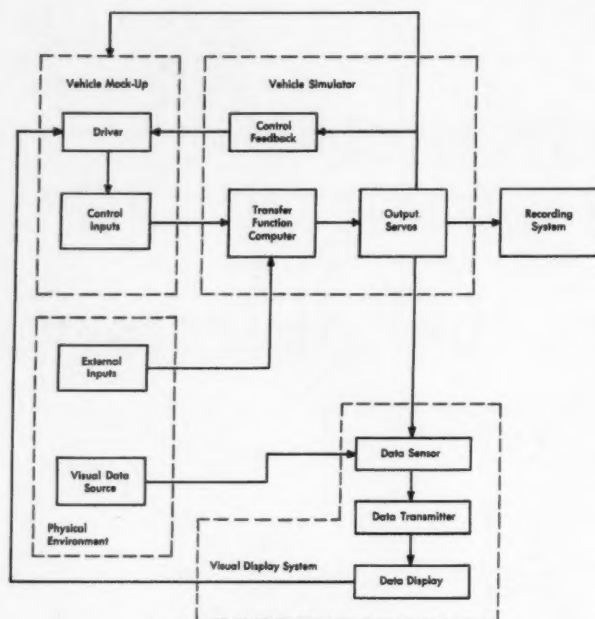


FIG. 2 — General Simulator System

driver inputs; and the driver's behavior is determined by the external environment and his physiological and psychological state. Thus, an understanding of the system can be achieved only by considering the interaction of a wide variety of factors.

Research programs of the Vehicle Dynamics Department of Cornell Aeronautical Laboratory have proved fruitful sources of information for all three elements of the transportation system. Although some of these programs are centered in the aeronautical field, past experience has shown that techniques of analysis and simulation developed for aircraft can be successfully transferred to other fields of dynamics.

The basic theory of automotive handling dynamics, using methods previously developed for similar aircraft stability and control problems, has been outlined

in a series of papers presented in England (see References). One important facet of the dynamics of the vehicle (one of the three aforementioned elements) is the force-producing characteristics of the tire. These properties have been experimentally investigated in a number of programs for commercial organizations and the military services. A more comprehensive theory of tire dynamics is currently being developed.

### Interaction of Road and Vehicle

The dynamics of road loading is another challenging phase of the transportation system now under study at CAL. In this case the physical interaction of the road and vehicles is emphasized and the physiological environment to which the driver or passengers are subjected is an important subsidiary consideration. Here the human engineering capability of the Vehicle Dynamics Department comes into play. Carry-over from work sponsored by the military in the field of human performance has been helpful in the area of driver behavior.

Several techniques can be employed to study the performance of a highway system; however, when the driver is the center of interest there are only two methods available. One is to measure under actual driving conditions the behavior of the driver and the environmental factors which influence him. The other is to make similar measurements under simulated conditions. The choice of methods is based on the degree of reality required in the study and the hazards which might be associated with specific test conditions.

The first method is double-edged, for it is obvious that a simulator will never be as real as reality itself. On the other hand, reality may be too "real" for experimental purposes — i.e., there are so many factors in the real situation that are not easily controlled or reproduced that experimental data will always contain wide variations. Furthermore, it is not always desirable to approximate reality. For some research purposes a symbolic presentation which introduces psychologically similar situations is sufficient. Our purposes are served, however, by considering only the aspects of simulating reality.

### Driving Simulator Preferred

The second method also has two facets — no matter how desirable safety is, the hazards involved in driving definitely affect the driver's performance. If those hazards are completely removed, as in a simulator, then the driver's response to what would in reality be a potential accident situation may be drastically influenced. Be that as it may, the experimenter cannot legally or morally assume responsibility for accidents and therefore has no choice but to resort to non-highway conditions. For controlled experimental studies, then, the simulator is generally preferred since it does permit repetition of situations and it does remove the possibility of injury.

Is it feasible to construct a driving simulator? This question must be answered before such a device is designed and built. Involved in the answer is the type

## THE COVER

Problems of all-weather carrier operations have been investigated by the Laboratory under contract to the U.S. Navy. Among the project tasks has been development of a Wave Off and Transition Control Unit (WOTCU). The heart of WOTCU is a digital computer which helps to effect an efficient landing sequence and provide for emergency

landings and wave-offs. Here, a CAL physicist adjusts a part of the computer housed in a special trailer on the Laboratory grounds. Buffer equipment designed by the Laboratory for input to and output from the computer is installed in relay racks down the center of the trailer.

of simulation that is desirable. Simulators in which human beings are an integral part can be either mechanically exact or psychologically equivalent — or both. There are several cogent arguments for either type, but since driver performance in a prescribed physical environment is of primary concern, direct mechanical simulation is preferable. A feasibility study based on such simulation has just been completed by CAL under sponsorship of the U. S. Department of Health, Education and Welfare, Division of Special Health Services.

#### Simulator is Described

Determination of feasibility starts with a simplified description of the simulator that defines major components and the relationships between them. Thus, as in Fig. 2, the components are the Vehicle Mock-Up, Vehicle Simulator, Visual Display, and Physical Environment. Each of these components must be ex-

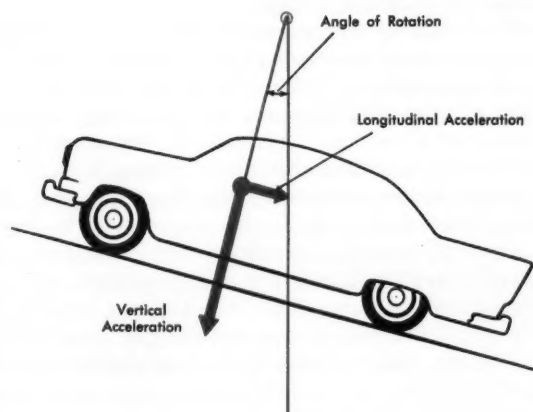


FIG. 3 — Simulation of Longitudinal Acceleration

amined in terms of its characteristics in reality. What physical variables are inherent? What is the range of these variables? How are the variables related? Once these quite complex questions are answered, the next step is determining how each variable can best be simulated. Finally all of the individual simulators must be combined to produce a complete simulator.

The Vehicle Mock-Up contains the driver, his control elements (steering wheel, throttle and brakes), and a conventional interior physical environment. The most economical way of incorporating this component is to start with a real car and add the required instrumentation and connections to the remaining components of the simulator. It is reasonable to conclude that this approach is feasible, even before other aspects of the simulator have been examined.

The Vehicle Simulator determines the dynamic behavior of the Mock-Up. The simulator receives inputs from the control elements and from external sources (road surface and wind), and reproduces correct motion responses in the Mock-Up. For convenience, the vehicle simulator can be separated into three response modes: performance simulation, ride simulation, and

handling simulation. The division is based on the dynamic equations of motion, which show the three modes to be practically independent for a wide range of conditions.

Performance includes longitudinal motion (forward or rearward velocity and acceleration) and the sounds associated with engine operation and aerodynamic effects. In reality, relative velocity is sensed visually by awareness of the passage of objects in the external environment; thus, in the simulator this aspect of performance must be presented by the visual display.

Acceleration, on the other hand, is manifested by stimulating pressure receptors and by audible changes in engine noise. Actual engine operation or taped recordings can be used for the sound effects, but the former is preferred since true reproduction can be realized. Caution must be exercised, however, since overemphasis of engine sounds drastically affects speed estimates in a simulator.

#### Simulating Acceleration

Although acceleration effects are not capable of exact reproduction over large ranges of time and amplitude, two approximate solutions have been suggested and examined. Longitudinal acceleration can be simulated by rotating the automobile and visual display about a horizontal axis, thus producing apparent longitudinal accelerations (Fig. 3). If the rotating angle is small, it is proportional to longitudinal acceleration. This is satisfactory for constant accelerations, but when acceleration changes with time, rotation angle also changes and other, undesirable, components of acceleration are produced.

These effects suggest a second possibility, in which longitudinal acceleration is simulated by producing angular accelerations about a fixed point. Exact reproduction is accomplished when the rotation axis is at an infinite distance from the vehicle, but approaching this distance is obviously impractical for a simulator. As the rotation point moves closer to the vehicle, accelerations other than the desired ones are again produced.

A third method tried in Europe uses an inflatable seat cushion, in which both the inflation pressure and seat contour are changed as functions of the acceleration analog. In combination with the visual display and other cues this appears to create a sensation of dynamic motion.

The ride mode is a function of the geometry of the road surface and the vehicle suspension system. Mechanization of this part of the simulator is not complicated and could consist of servo actuators that drive through the tires with a motion that duplicates the road profile. Smooth or rough roads, joints, and other surface characteristics could be represented.

Simulation of the handling mode is quite complicated mechanically. The relationship between steering wheel motion and car response depends heavily upon tire properties and road surface. Solution of the equations by electronic analog computer techniques provides the basic input-response information. The

actual response is manifested partly in motion of the vehicle mock-up itself and partly in apparent motions occurring in the visual display. Since visual cues are essential to driving, the relative motion of the visual display must be highly realistic. Thus, precision in this part of the simulator is essential.

#### Visual Display is Critical

Visual displays, the key to successful simulation, have been the subject of many intensive investigations. In the driving simulator it is desirable to present all of the normal visual environment to the driver — a hemispherical display in full color, fine detail, and stereoptic vision. Something less will probably be attainable, at least in the near future. CAL's studies have disclosed that closed circuit TV linking a model of the local topography to a wide-angle projection system will ultimately produce the best display.

It is vital that the visual display be unprogrammed. The driver must be free to maneuver as whim or circumstances dictate and the visual scene must change correspondingly. Freedom to maneuver is an obvious requirement that has fundamental ramifications within the concept of an "expectancy model." Here, the driver's experience leads him, in a given situation, to expect certain events to happen. If the simulator is unprogrammed and correlates well with reality, the driver will realize his expectations. However, if the visual display does not change as the driver maneuvers (i.e., the display is programmed) then he will not realize his expectations and will never be able to associate the simulation with a real driving task.

Of the methods available for producing visual displays, motion pictures have the best optical characteristics but produce an inherently programmed display. Such direct viewing systems as the unit-power telescope are unprogrammed and give high quality images in full color, but have mechanical disadvantages. Point-light source projection techniques are being used both in helicopter and automobile simulators, but are limited in resolution and brightness. TV systems are also limited in resolution, contrast, and brightness, but appear to have a greater potential for development than other methods.

#### Improvements Due in TV Systems

Several interesting techniques now under development will produce a marked improvement in TV systems. First, greater resolution will be obtained through increases in the number of lines scanned per picture frame. A two-fold improvement (from 525 lines) is available and improvements up to tenfold are being developed. Increased resolution permits a larger field of view as well as greater detail to be presented. Second, greater contrast and brightness are available through light amplification techniques. The Eidophor system, already successfully demonstrated, uses the distortion of a film caused by electrostatic charges from the TV cathode ray tube to modulate a high-intensity light source. Thus, brightness is a function of the light source rather than of the basic television system.

In normal driving the field of view is relatively unlimited in azimuth, but is restricted vertically by the automobile. Most present-day simulators are restricted to relatively narrow fields similar to that available in wide-screen motion pictures. In fact, some of the popular expanded-screen projection systems received their development impetus from simulator developments.

A system that has considerable promise for full 360-degree presentation was initially developed by Bell Aircraft and recently studied by CAL. The Bell system is based on the reflective properties of conic sections. Light rays directed toward one focus of an ellipse or hyperbola will be reflected through the other focus of these figures. Thus, by appropriately combining conic mirrors of revolution, a simple, 360-degree, unit-power telescope can be built. For the automobile simulator this is used as a TV projection system, although it could be used with motion pictures or as a direct-viewing optical system.

#### Role of the Driving Simulator

The foregoing points make it clear that it is feasible to build a driving simulator. However, a basic question should be considered first — "How will such a device make positive contributions to improving highway transportation systems?" Perhaps the best answer is to consider a typical area that needs investigation.

Since accident reduction is the immediate goal, one of the first considerations is the behavior of the driver in potential accident situations. Key points are the physical actions taken by the driver, and the psychological reaction produced in the driver as a function of his physical and mental state and the specific situation. A thorough study of this single area should provide knowledge of the physical factors that produce accident situations, the ability of the driver to recognize these situations, the capability of the driver to avoid accidents once the situation is recognized, and the types of maneuvers performed by the driver.

Such a study would consist of a series of planned simulator experiments covering the predominant types of accidents and a broad sample of drivers. Test data in the form of action time histories (vehicle speed, position, direction, driver control actions, physiological data, etc.) and personal historical data would be carefully analyzed by statistical methods to determine the relative significance of each variable.

Improvements in the basic system elements can follow from the conclusions reached in the research programs. Such factors as highway design, traffic control, automotive handling qualities, and driver training can be affected by the type of information obtained from experimental programs in a simulator. In particular, the type of research outlined can provide a rational approach to the design and legislative control of transportation systems.

#### REFERENCES

- Five papers on "Research in Automobile Stability and Control." See listing on back page.
- Hutchinson, C. H., "Automobile Driving Simulator Feasibility Study," Report No. YM-1244-V-6, Nov. 18, 1958.

# AIRBORNE

# Electricity . . . .

By Dr. JAMES W. FORD

Most people are aware of the existence of the earth's magnetic field. Relatively few, however, know that the earth's atmosphere supports an electrostatic field which has an intensity of 100 to 200 volts per meter at the earth's surface.

Knowledge of this field and its temporal behavior enters into studies of weather, air pollution, thunderstorm electrification, and airborne communications, to name but a few of the areas being investigated as part of CAL's atmospheric physics program.

The earth and the ionosphere serve as the concentric plates of a spherical condenser between which this electric field exists. During fair weather the earth is usually the negatively-charged plate of that condenser and the ionosphere is the positively-charged plate. The field between them is said to be negative. During stormy weather the field may reverse its polarity and become positive.

The atmosphere between the plates is more than just a gas made up of individual molecules of oxygen, nitrogen, carbon dioxide, argon, etc. It also contains many clumps of perhaps eight or ten individual molecules which have joined after chance encounter; it bears sub-microscopic particles of varied chemical description; it carries visible — often noxious — industrial pollutants; and it holds a great deal of water in the form of vapor.

## Characteristics of the Constituents

These atmospheric constituents have two characteristics which make them interesting to the atmospheric physicist. First, some of them become electrically charged, or ionized, by the action of cosmic radiation and radioactivity from the soil. Second, many of them are of such a physical or chemical nature that atmospheric moisture condenses upon them so that they

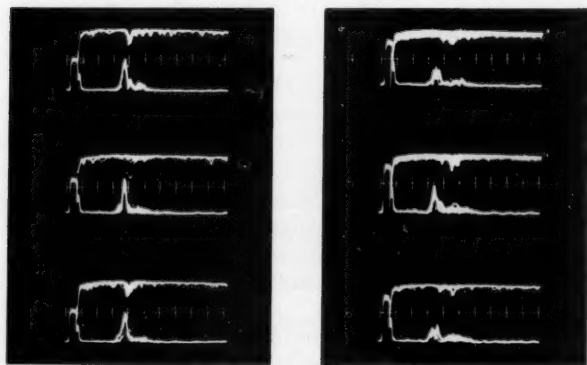


FIG. 2 — Radar pulses reflected from the aurora at different frequencies. Upper trace in each oscillogram shows the 226 megacycle echo, lower trace is at 49.7 megacycles. The range scale here is about 100 miles per division.

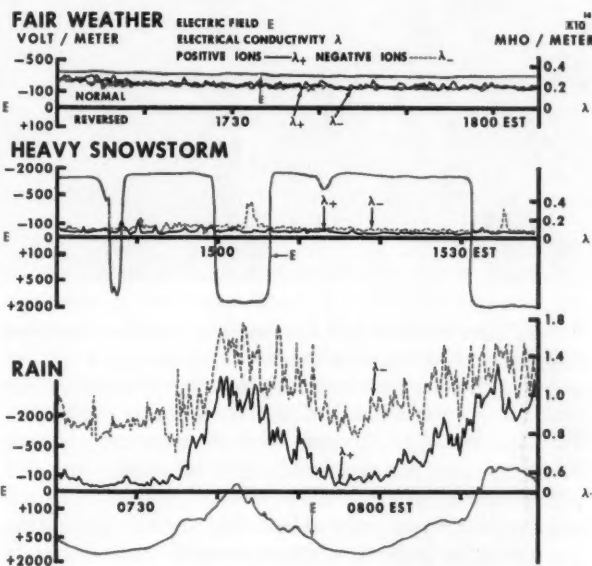


FIG. 1 — Electric field and conductivity records made in fair weather, in a heavy snowstorm and in a rainstorm. The nearly constant field in fair weather is in marked contrast with the disturbed field in a rainstorm and the abrupt changes in polarity in a snowstorm.

may serve as centers for droplet or ice crystal formation. Known as "condensation nuclei" and "freezing nuclei," they initiate the formation of fog, clouds and snow.

The realm of atmospheric electricity, then, embraces the earth's electric field, the charged particles or ions which move in the atmosphere under the influence of that field, and the condensation and freezing nuclei which help control the form in which water appears.

It is difficult to determine which characteristics of atmospheric electricity are basic, world-wide ones and which are due largely to localized influences. In general, the latter appear to predominate in measurements made in Western New York by CAL. Just as our weather patterns have distinct local characteristics, so does the atmospheric electrification in the region have recognizable distinctions.

## Extensive Program in Atmospheric Electricity

Some of these characteristics were revealed in a two-year investigation by Cornell Lab's "atmospheric electricians" for the U.S. Air Force. Carried out around the clock, the program was designed to detect relationships between atmospheric electrification and weather phenomena. The CAL experiment measured temperature, humidity, wind speed and direction, precipi-

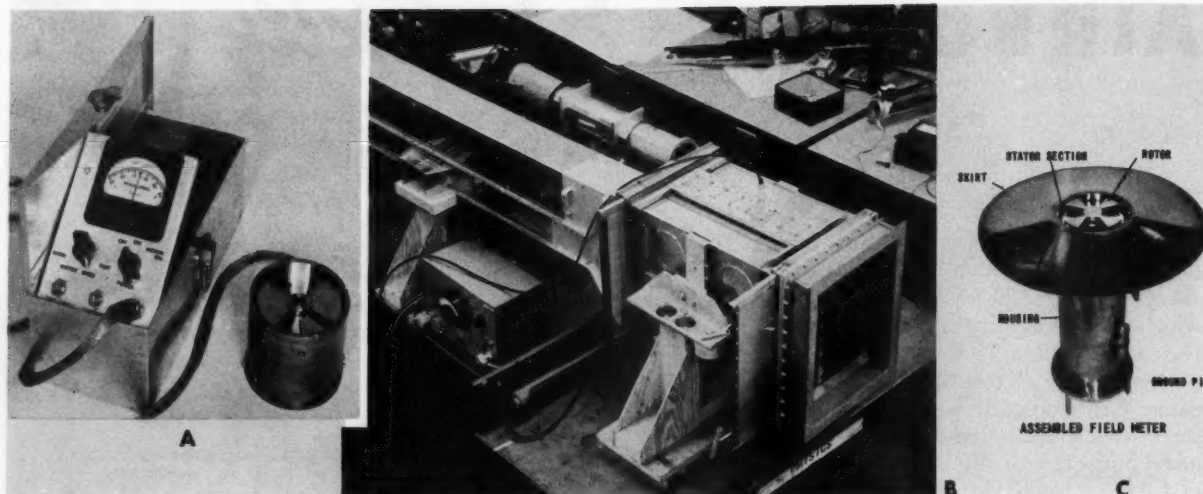


FIG. 3 — Some of the instrumentation developed by CAL for atmospheric electricity research: (a) a portable generating voltmeter, (b) an atmospheric ion counter, (c) an all-weather atmospheric electric field meter.

tation, electric field, and atmospheric conductivity due to positive and negative ions.

Electric field and conductivity records made in fair weather were smooth and slowly changing; those for disturbed weather showed marked variations, as one might expect. Records made in a rainstorm were of a particularly ragged quality because of charge created by the shattering rain drops, an erratic generating mechanism at best. In contrast, records made during a severe snowstorm showed the presence of high fields of almost constant magnitude, but with abrupt changes in polarity at quite regular intervals (Fig. 1).

That any charge distribution in snow clouds could reverse its polarity as rapidly as these electric-field records suggest was considered to be a physical impossibility. Consequently another snowstorm showing the same field behavior was examined with a radar "probe," i.e., a radar beam was directed upward into the storm while electric field observations were being made.

#### Mechanism of the Field Reversal

An exact match in the timing of electric field changes and of rapid movement of the storm centers (the radar targets) revealed the probable mechanism of field reversal. Storm centers overhead moved downward — upward on the next swing — as if carried by massive vertical drafts. Whenever the cloud fell, its lower charged portions — in this case negative charge — merged with the surface charge of the earth. The cloud then behaved as a positively charged monopole. When the cloud lifted, it regained its lower (negative) charge, and the electric field reverted to its original configuration.

It is now clear from the CAL studies that atmospheric electrification effects may be excellent indicators of localized weather features but that only rarely can they be used to predict weather behavior on a large scale. Nevertheless, there is evidence available that a network of atmospheric electricity stations allied with weather bureau installations could provide much valuable data. Navy scientists already are using such equipment to assist in predicting fog at shoreline installations.

#### Thundercloud Electrification Studied

Lightning in thunderstorms is evidence that electrification is involved in storm generation. Lightning strokes are thought to serve one highly useful purpose, i.e., to replace the charge which is constantly leaking away from the earth's surface during fair weather. If it were not for this mechanism, or another of similar magnitude, the earth would be without charge in less than 15 minutes!

About ten years ago a CAL physicist, seeking data on storm electrifications, measured thunderstorm potentials by means of a corona point radiosonde. He found that his data, although apparently correct in terms of precise laboratory calibrations, did not agree with evidence gained by other methods. His continuing research led to a series of tests at CAL which delineated the role space charge plays in suppressing corona current during still-air measurements, and the influences of windage, barometric pressure, and corona point potential on corona discharge behavior. Based on a new interpretation of calibration data, the older thundercloud corona discharge values were increased about ten times and are now compatible with other measurements.

#### Properties of Ionosphere Studied

Within the past two years CAL has added to its atmospheric physics program an investigation of properties of the ionosphere. This work has been performed for the Air Force Cambridge Research Center. Characterized by an altitude range of 50 to 600 miles, the ionosphere is notable for its free electron content and

This concludes Dr. Ford's series of two articles on atmospheric physics. The first article, dealing with cloud physics and weather modification, appeared in Vol. VI, No. 3 of *Research Trends*.



FIG. 4 —A corona-point discharger installed on a B-29 airplane, part of a system for neutralizing the electrostatic charge induced on an aircraft during flight.

the fact that most of its gaseous constituents are in atomic, rather than molecular, form.

One well-known ionospheric phenomenon is the aurora borealis, the northern lights, whose brilliant drapery-like electric displays reflect radio energy almost as if a metallic grid hung in the sky.

To study the fine structure of the aurora CAL scientists are currently firing radar pulses to the north. Two different radio frequencies are being used; a third will soon be added.

These experiments reveal that the aurora reflects radar pulses from different ranges depending upon radio

frequency (Fig. 2). Sometimes only one or the other of the two reflecting layers so far noted will be evident. On occasion, both appear. It is hoped that the addition of a third pulsed frequency will determine whether there is further depth to the aurora's structure.

Instrumentation has been one of CAL's major contributions to the field of atmospheric electricity. Invariably of a special-purpose nature, our developments include electric field meters, atmospheric ion counters, and corona point devices for aircraft discharge, all of them used on CAL projects. (See Fig. 3.)

The corona-point unit (Fig. 4) was part of a unique airborne charge control system. Electric field meters sensed electrostatic charge on the airplane and servo-controlled a high-voltage feed to the points so as to neutralize charge from the atmosphere.

There is a growing tendency to look for weather influences at higher and higher levels in the atmosphere, especially in the ionosphere. Frontal disturbances, in particular, seem to reflect high altitude control. Observations of atmospheric electrification may serve to track thunderstorms or reveal the occurrence of other major atmospheric disturbances. Studies of the aurora may show high-energy particles and radiation thrown out from the sun can linger in near-by space and spill out to form the displays at which we wonder! Whatever their nature, the phenomena of atmospheric physics will continue to interest CAL scientists.

#### REPORTS

"Study of the Earth's Electrical Field," RA-764-P-15; Garber, David; June, 1955.

"Interim Report on Project Aurora," RM-1182-P-1; Flood, Walter; October, 1958.

"Condensation Nuclei Experiments with Simple Apparatus," Weatherwise, Vol. II, No. 6; December, 1958; Justo, James, and Pilié, Roland.

#### ABOUT THE AUTHORS

CHARLES H. HUTCHINSON, Head of the Engineering Section of the Vehicle Dynamics Department, had a wide background in structural design, stress analysis, and design of hydraulic and servo systems to bring to his work on the driving simulator, described in "Driving Comes Into the Laboratory."

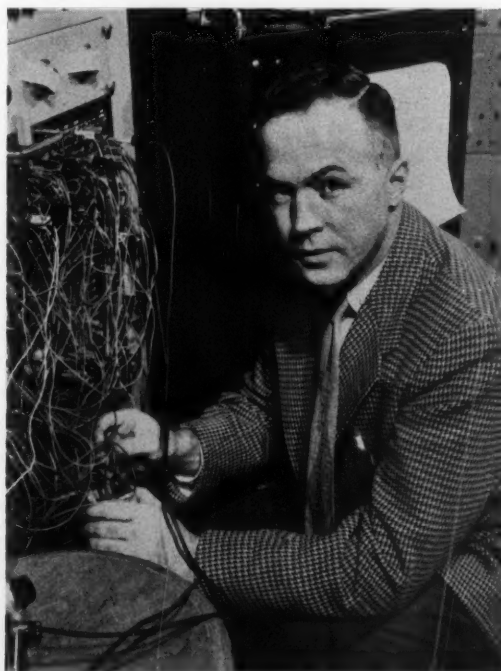
He joined CAL's Flight Research Department in 1954 and for a year and a half acted as project engineer on development of equipment for a moment-of-inertia program. He was appointed to his present post shortly after the Vehicle Dynamics Department was formed in 1956.

Mr. Hutchinson was formerly a controls designer on the F4D Skyray project at Douglas Aircraft Corp. He was also active in research and development of atomic ordnance for the Sandia Corp.

He received the B.S. and M.S. degrees in Aeronautical Engineering from the University of Minnesota. He was separated from the U.S. Navy in 1946 with the rank of Ensign.

Mr. Hutchinson is a member of the Institute of the Aeronautical Sciences and the American Society for Metals.

DR. JAMES W. FORD's biographical sketch accompanied his first article in the Fall issue of Research Trends. Immediately following the appearance of that article Dr. Ford was appointed Head of the Applied Physics Department.



The Laboratory invites requests for its unclassified publications as a public service. Supplies of some publications are limited; and those marked with an asterisk may be distributed only within the United States. Please direct your request to the Editor, Research Trends, Cornell Aeronautical Laboratory, Buffalo 21, New York.

"RESEARCH IN AUTOMOBILE STABILITY AND CONTROL," five papers presented before The Institution of Mechanical Engineers, London, England; Nov. 1956. (Note: All five papers are bound as a single volume.)

1. "General Introduction to a Program of Dynamic Research," Milliken, William F. and Whitcomb, David W.; 23 pages.

This paper introduces an investigation of the fixed-control directional characteristics of automobiles, and those mechanical properties of tires used in the analysis of car stability and control.

2. "Theoretical Prediction and Experimental Substantiation of the Response of the Automobile to Steering Control," Segel, Leonard; 21 pages.

Classical mechanics is applied to the automobile in order to study the lateral rigid-body motions produced by steering control.

3. "A Device for Measuring Mechanical Characteristics of Tires on the Road," Close, William and Muzzey, Clifford L.; 17 pages.

This paper describes a machine which measures the mechanical force and moment characteristics of pneumatic tires moving over flat road surfaces.

4. "Tire Tests and Interpretation of Experimental Data," Fonda, Albert G.; 19 pages.

The test techniques and associated equipment developed for use of the Air Force-Cornell Tire Tester have permitted road tests yielding unique data on the cornering characteristics of pneumatic tires.

5. "Design Implications of a General Theory of Automobile Stability and Control," Whitcomb, David W. and Milliken, William F.; 25 pages.

The lateral-directional motions of an automobile are studied by means of equations of motion derived for a vehicle assumed to have yawing and sideslip degrees of freedom only, and travelling at a constant forward speed.

"SHOCK TUBE DRIVER TECHNIQUES AND ATTENUATION MEASUREMENTS," Wittliff, Charles E. and Wilson, Merle R.; CAL Report No. AD-1052-A-4; August 1957; AFOSR TN 57-546; ASTIA No. AD-136-531; 38 pages.

The development of the hypersonic shock tunnel at CAL has been accompanied by a study of various techniques for producing strong shock waves to drive the shock tunnel. The results of this study are described as to technique and relative efficiency of different driver gases, and the resultant attenuation of the shock wave in the low pressure tube.

"SINGLE-PULSE SHOCK TUBE STUDIES OF THE KINETICS OF THE REACTION  $N_2 + O_2 \rightleftharpoons 2NO$  BETWEEN 2000-3000°K," Glick, H. S., Klein, J. J., and Squire, W.; CAL Report No. AD-959-A-1; AFOSR TN-57-407 under contract AF 18(600)-1332; September 1957; 28 pages.

The single temperature pulse technique, developed at the Cornell Aeronautical Laboratory, has been used to study the kinetics of the formation of nitric oxide in the temperature range from 2000° to 3000°K. It has been found that the kinetics of the reaction are consistent with the chain mechanism proposed by Zeldovich.

"A LABORATORY STUDY OF CONTRAILS," Pilié, Roland J. and Justo, James E.; Reprinted from the Journal of Meteorology, Vol. 15, No. 2; April 1958; 6 pages.

Contrails were produced for laboratory study by burning aircraft fuels under controlled conditions of ambient temperature and humidity at pressure altitudes between 1000 and 300 mb. Laboratory experiments with these trails proved that the initial phase of the condensed moisture is liquid and produced strong evidence that, contrary to general belief, the final phase is sometimes liquid.

"DRAG DUE TO LIFT OF A NOT-SO-SLENDER CONFIGURATION — APPLICATION OF THEORY," Part II, Vidal, Robert J.; CAL Report No. AF-996-A-2; March 1958; 22 pages.\*

Cheng's second-order theory for minimizing the supersonic drag due to lift of rather nonslender wing-body combinations is briefly described and the restrictions on the theory are reviewed. Methods are presented for applying the theory in aircraft and missile design with appropriate design charts for predicting the chordwise lift distribution of wing-body combinations. The drag due to lift is calculated for three configurations and the significance of these calculations is discussed.

"SHOCK WAVE AND FLAME INTERACTIONS," Rudinger, George; Paper prepared for the third colloquium of the AGARD combustion and propulsion panel, Palermo, Sicily; March 1958; 24 pages.

When a shock wave interacts with a laminar flame, the latter emits pressure waves during a short time after the interaction in addition to the immediately established and transmitted and reflected waves. Schlieren photographs show how the flame is broken up as a result of the shock acceleration. The subsequent increase of the flame surface is accompanied by an increased rate of combustion which is associated with the emission of secondary pressure waves.

"A PHILOSOPHY OF AIR-DATA MEASUREMENT," Andersen, N. Y. and Bogdan, L.; Reprinted from the Aeronautical Engineering Review, Vol. 17, No. 3; March 1958; 4 pages.

The approach described in this paper is based on the use of a single pressure-type probe that provides a direct sampling of the local (airframe-distorted) air stream.

"THE REFLECTION OF SHOCK WAVES FROM AN ORIFICE AT THE END OF A DUCT," Rudinger, George; Reprinted from the Journal of Applied Mathematics and Physics (ZAMP), Vol. IXb, No. 5/6 1958; 16 pages.

It was observed that when a shock wave reaches an orifice plate at the end of a duct, the pressure at the head of the reflected wave rises higher during a short pulse ('overshoot') than can be accounted for by the conventional computing methods.

